

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>2005</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2005 to 00-00-2005</b>	
4. TITLE AND SUBTITLE <b>Improving the Characterization of the Battlespace Environment with Satellite Brightness Temperature Assimilation</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Research Laboratory, Marine Meteorology Division, 4555 Overlook Avenue SW, Washington, DC, 20375</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>3</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## IMPROVING THE CHARACTERIZATION OF THE BATTLESPACE ENVIRONMENT WITH SATELLITE BRIGHTNESS TEMPERATURE ASSIMILATION

N.L. Baker, C.B. Blankenship, W.F. Campbell, and T.F. Hogan

*Marine Meteorology Division*

R.L. Pauley

*Fleet Numerical Meteorology and Oceanography Center*

**Introduction:** Satellite observations, particularly in data-sparse regions, are critically important for initializing the Navy's global and mesoscale numerical weather prediction (NWP) models used to provide tactical weather support. Advanced Microwave Sounding Unit A (AMSU-A) and AMSU-B are multichannel passive microwave radiometers that provide global observations of atmospheric temperature and moisture, respectively. Recently, the NRL Atmospheric Variational Data Assimilation System (NAVDAS) began operational assimilation of AMSU-A brightness temperatures  $T_b$ 's for the Navy Operational Global Atmospheric Prediction System (NOGAPS), replacing the assimilation of temperature retrievals. AMSU-A assimilation significantly improves the Northern and Southern Hemisphere forecast skill and tropical cyclone track predictions. Assimilation of AMSU-B humidity profiles improves the representation of NOGAPS upper-tropospheric water vapor, and further reduces tropical cyclone track forecast error.

### Motivation for Radiance Assimilation:

NAVDAS was developed to assimilate satellite observations effectively. For satellite observations such as AMSU-A/B, radiative transfer theory relates the outgoing radiation to the vertical profiles of atmospheric temperature and moisture, and surface emissivity and skin temperature. Traditionally, satellite  $T_b$ 's were used to retrieve temperature and humidity profiles. Because  $T_b$ 's are integrated measurements with contributions from deep layers in the atmosphere, and are also imperfect, the retrieval problem is mathematically ill-posed; many possible vertical profiles of temperature and moisture may yield the same  $T_b$ . Consequently, retrieval errors are complex and difficult to specify correctly;  $T_b$  errors are simpler to characterize. Accurate error specification is required for proper observation weighting in the assimilation system as well as quality control and bias correction.

Because the relationship between the observed AMSU-B  $T_b$ 's and atmospheric water vapor is strongly

nonlinear, direct assimilation of AMSU-B  $T_b$ 's will require modifications to NAVDAS. As a first step, the water vapor profiles retrieved from AMSU-B are assimilated.

### Implementation of AMSU-A/B Assimilation:

Successful assimilation of satellite  $T_b$ 's requires careful channel selection and quality control, primarily to screen out observations with a strong signal from variables that are not well represented in the NWP model (e.g., cloud liquid water) or the radiative transfer model (e.g., scattering by precipitation). Recent NOGAPS changes implemented to make AMSU-A/B assimilation more effective include raising the model top and improving the model moisture fields and skin temperatures over land.

Bias correction is an essential component of radiance assimilation, as the innovations (differences between the observed and forecast  $T_b$ 's) are often larger than the signal. The biases are satellite-specific—the same sensor flown on two different satellites will have different bias characteristics. Because these biases also vary with time, an automated bias coefficient updating system was developed for operational use at Fleet Numerical Meteorology and Oceanography Center (FNMOC). After each analysis cycle, new bias correction coefficients are calculated, tested, and updated without user intervention. If the new coefficients fail any test, the previous coefficients are retained and a brief problem summary is automatically emailed to the user, affording quick evaluation of potential problems both operationally and for research experiments.

**NOGAPS Forecast Improvements with AMSU-A/B Assimilation:** On June 9, 2004, NAVDAS began operational assimilation of AMSU-A  $T_b$ 's for NOGAPS, replacing the assimilation of temperature retrievals. AMSU-A assimilation substantially improves the height, wind, and temperature forecasts for both hemispheres at all forecast lengths. For example, the two- to five-day NOGAPS forecast, as measured by the 500 hPa anomaly correlation, is increased by 5 to 7 h in the Northern Hemisphere (Fig. 7(a)), and by 14 to 16 h in the Southern Hemisphere (Fig. 7(b)). Similar improvements are observed at other levels, along with significantly fewer forecast “busts.” Both the NAVDAS analyses and NOGAPS forecasts exhibit better fit with radiosondes. The predicted tropical cyclone tracks, which are critically important to the Navy, show error reductions (Fig. 8) up to 25 nautical miles (verified against Joint Typhoon Warning Center and National Hurricane Center post-

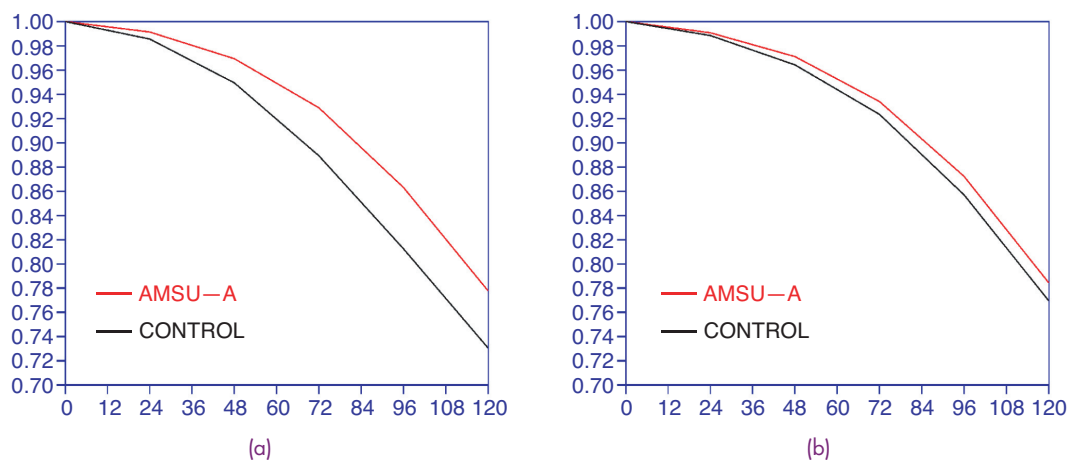
season best tracks). The operational implementation of AMSU-A assimilation at FNMOC is one of the most important advances to NOGAPS in the past decade and is equivalent to 9 to 12 years of general system improvements.

Extensive testing indicates that AMSU-B water vapor retrieval assimilation corrects for known model biases by drying out the middle and upper troposphere. Moisture features are better represented, as validated by geostationary infrared observations (Fig. 9) and stronger gradients. Overall, tropical cyclone forecasts are better with AMSU-B, with smaller errors in the forecast track and central pressure (Fig. 8). Transition of AMSU-B retrieval assimilation to FNMOC operations is targeted for 2005.

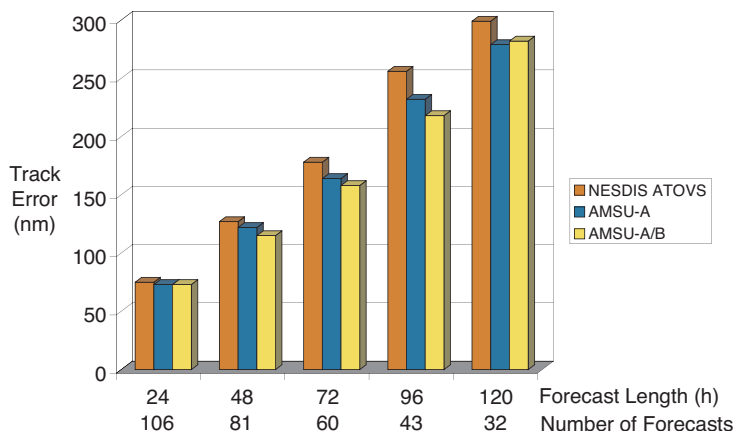
**Looking to the Future:** In the near term, NAVDAS will soon become operational for the Navy's

mesoscale NWP model (COAMPS™—a trademark of the Naval Research Laboratory) at FNMOC, paving the way for improved analyses, forecasts, and tactical decision aids due to AMSU-A/B assimilation.

Over the next decade, the ability of polar-orbiting and geostationary satellites to observe the Earth environment will improve dramatically, largely due to the combined DoD and civilian National Polar Orbiting Environmental Satellite System (NPOESS). NRL scientists, along with their partners in the Joint Center for Satellite Data Assimilation, are actively developing assimilation techniques to be able to effectively utilize these new observations. While the costs of developing specialized satellite assimilation techniques are significant, the recent successes at NRL and other NWP centers have clearly demonstrated that substantial gains in analysis and forecast skill can be made through assimilation of these observations.



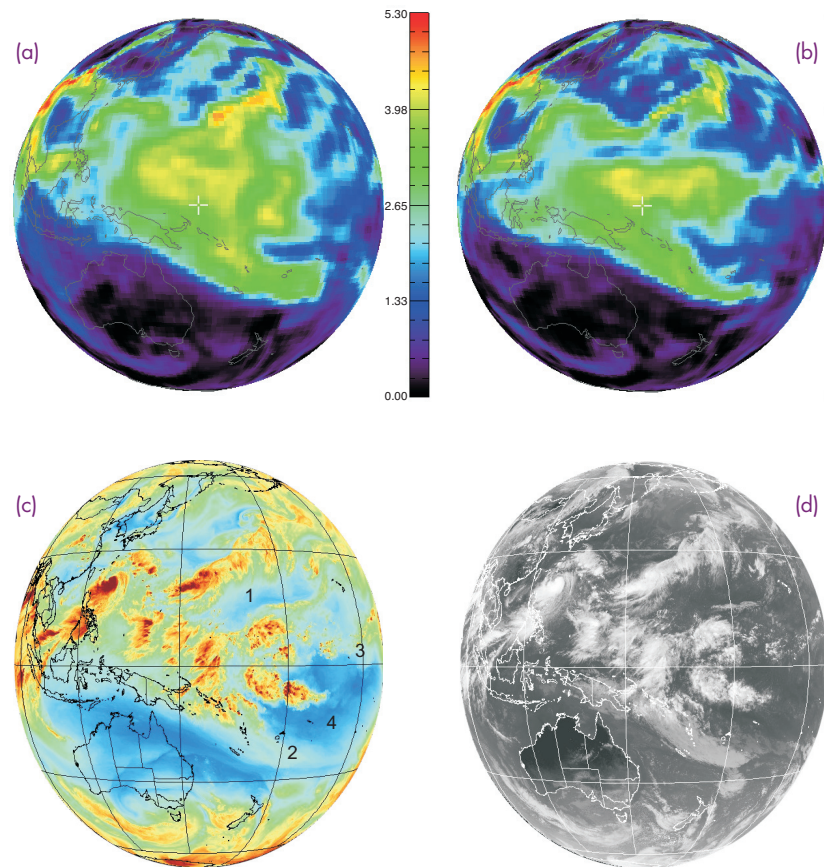
**FIGURE 7**  
(a) Southern Hemisphere and (b) Northern Hemisphere 500 hPa height anomaly correlation vs forecast hour for July 16 to September 30, 2003. The test run (AMSU-A) included NAVDAS assimilation of AMSU-A  $T_b$ 's, while the control run assimilated NESDIS ATOVS retrievals with NAVDAS.



**FIGURE 8**  
Comparison of the mean tropical cyclone track error vs forecast hour for the month of September 2003. Verification is against the postseason "best track." The numbers below the forecast length are the total number of forecast tracks for the month used in the comparison.

## References

- <sup>1</sup> N.L. Baker and W.F. Campbell, "The Impact of AMSU-A Radiance Assimilation in the U.S. Navy's Operational Global Atmospheric Prediction System (NOGAPS)," preprints, 13th Conference on Satellite Meteorology and Oceanography, Norfolk, VA, 2004.
- <sup>2</sup> C.B. Blankenship, E.H. Barker, and N.L. Baker, "Assimilation of AMSU-B Humidity Profile Retrievals Using the NRL Atmospheric Variational Data Assimilation System (NAVDAS)," preprints, 13th Conference on Satellite Meteorology and Oceanography, Norfolk, VA, 2004.



**FIGURE 9**

(a) Analyzed 500 hPa specific humidity ( $\text{g kg}^{-1}$ ) at 06Z on August 10, 2004, control run; (b) AMSU-B run; (c) GOES-9  $6.7 \mu\text{m}$  water vapor channel image at 0525Z; (d) GOES-9 infrared image at 0525Z. Features improved in the AMSU-B run include (1) dry channel north of the Intertropical Convergence Zone (ITCZ), (2) sharp feature at tail of South Pacific Convergence Zone, (3) sharp gradient in ITCZ, and (4) shape of dry region in Central Pacific.